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# ENVIRONMENTAL TESTING STANDARDIZATION VIA MIL-STD-810

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Aeronautical Systems Division
Wright Patterson Air Force Base, Ohio

November 1962

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ASTEWC TECHNICAL MEMORANDUM 63-1

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Task 130906


AERONAUTICAL SYSTEMS DIVISION

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AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

## FOREWORD

MIL-STD-810 (USAF) "Environmental Test Methods for Aerospace and Ground Equipment" was prepared by the Environmental Criteria Branch, Environmental Division, Directorate of Engineering Test, Deputy for Test and Support under Project 1309, Task 130906 to satisfy an urgent need for one standard environmental test document for USAF weapon systems. The Project Engineer on this effort was Mr. V. J. Junker of the Environmental Criteria Branch.

ABSTRACT

This report acquaints the user of MIL-STD-810 with the background, preparation, application, and problem areas encountered in the promulgation of the Standard. Charts are provided which illustrate the transition from environmental tests specified in MIL-T-5422 "Environmental Testing for Aircraft Electronic Equipment", MIL-E-5272 "Environmental Testing, Aeronautical and Associated Equipment", MIL-E-4970 "Environmental Testing, Ground Support Equipment", and MIL-A-26669 "Acoustical Noise Tests for Aeronautical & Associated Equipment" to like tests in MIL-STD-810. Problems associated with space environmental testing and combined environmental testing are also discussed.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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Deputy for Test and Support

# ENVIRONMENTAL TESTING STANDARDIZATION VIA MIL-STD-810

## SECTION I

## INTRODUCTION

MIL-STD-810 (USAF) "Environmental Test Methods for Aerospace and Ground Equipment", has been prepared to bring together into one document, procedures and guidance for the environmental testing of future generations of aerospace and ground equipment.

The general provisions of MIL-STD-810 include standard laboratory test methods for determining the environmental suitability of military hardware when used under similar service conditions, guidance to the system or equipment engineer formulating an environmental test program, and guidance for those preparing the environmental test portions of detail specifications. Contained in the standard are eighteen basic test methods with a total of twenty-six detailed test procedures. Excluded are tests for airframe structures and primary power plants. Tests required for these items, as well as design factors for broad coverage areas such as the suppression of radio frequency interference, effects of corrosive fuels and oxidizers, etc., which in a general sense constitute environments, are either adequately covered by existing specifications or, by their nature and complexity, must be treated separately.

## SECTION II

## BACKGROUND

Over the past several years, numerous complaints have been heard regarding the environmental test procedures contained in various military specifications. These complaints have ranged from comments that the military has failed to lead the state of the art in environmental criteria and testing to charges of redundancy, conflict, and inconsistencies in the performance of tests among various specifications. The problem is traceable, in part, to the gradual evolution of the system concept as implemented by the Air Force. It became increasingly apparent as system contractors began integrating various equipments, tested against different specifications, into highly complex flight vehicles, each with its own peculiar environmental profile. The growing problem of adequate environmental testing techniques and facilities was further hastened by breakthroughs in rocketry and the race for supremacy in space. Deficiencies in the overall environmental program, when viewed from the system level, became more and more apparent.

A study was subsequently initiated to determine what measures could be taken to bring about the standardization of environmental testing to support the system concept. Attention was focused on five specifications: MIL-T-5422, Environmental Testing for Aircraft Electronic Equipment; MIL-E-5272, Environmental Testing, Aeronautical and Associated Equipment; MIL-E-4970, Environmental Testing, Ground Support Equipment; MIL-A-26669, Acoustical Noise Tests for Aeronautical and Associated Equipment; and MIL-S-27507, Shock Test, Saw Tooth Pulse, which was about to be published. The result of the study clearly indicated the need for up-grading test procedures and criteria and establishing a single standard environmental test document. The decision was made to continue the effort by preparing a completely new environmental test document.

## SECTION III

## PREPARATION OF DOCUMENT

In preparing the general framework for the first draft of the standard it was decided that only general guidance, philosophy, and other criteria common to the majority of test methods would be placed in the basic portion of the document. Since some tests are likely to require frequent changes to keep pace with the state of the art, each test was assembled as a separate "method". This arrangement permits revisions to a particular test method without disrupting the entire document.

Having established the format, the organization of the individual test methods was next approached. Specifications MIL-T-5422, MIL-E-5272, MIL-E-4970, MIL-A-26669, and MIL-S-27507, which may be called donor specifications were reassembled by environment as raw data and critically analyzed. This "weeding out process" not only revealed discrepancies in and among the various tests for the same environment or condition, but also brought to light certain methods and tests which were still geared to pre-World War II technology. In this analysis the raw data were required to satisfy the following questions:

1. Were the environment and the purpose for conducting the test adequately described?

2. Were specialized apparatus, control of environmental conditions, and handling and mounting problems peculiar to the test item clearly defined?

3. Was the test itself presented in a clear and logical manner?

4. Were the technical parameters of the test "scientific" in the sense that the test engineer could rely on the results obtained? In most instances the raw data failed this test. The development of each test method was approached with caution and some apprehension regarding extensive changes to the technical organization and stress levels of the tests. It was assumed that the raw data derived from the donor specifications were essentially correct. This assumption eventually proved false in many cases.

After some months the first draft of the standard was ready for coordination with a request for comments and suggestions. A sincere engineering evaluation was wanted from the military and from the aircraft, aerospace, and electronic industries, as well as independent testing laboratories. A large response was not anticipated to this invitation for comments. Again, this complacency was engendered by the assumption that the donor data were correct.

Over two hundred copies of the draft were circulated. One hundred and eleven individual replies containing numerous comments were returned; this was a most rewarding response. The majority of these replies, particularly from industry, urged the continuation of the effort for one standard environmental document. A number of activities, both military and industrial, provided as many as four or five pages of detailed technical comment. These comments predominantly pointed out engineering deficiencies and other weaknesses in the test procedures, the data for which, almost without exception, were inherited from the donor specifications.

As was expected, some replies were received which challenged or repudiated the basic intent of the effort. It was suggested that better use be made of man-hours by revising the donor specifications, that the introduction of still another environmental document would only add to the general confusion. These allegations are answered thus. Patching up the old specifications was not considered realistic or expedient. Since they are related to specific items, i.e., aircraft electronic and ground support equipment, it was believed that any attempt to introduce into them advanced requirements at the overall systems level would pose serious problems. Further, the procedures involved in accomplishing routine changes for just one specification are most time-consuming. Considering the number of specifications involved and the need for resolving many technical differences, the attempt to catch up would have been infinitely perpetuated.

The months that followed were devoted to setting things in order. Based on the comments received, and on in-house engineering, each test was again analyzed, re-engineered, and re-edited many times. Not one test derived from the donor specifications remained completely unchanged. Some test methods underwent extensive engineering effort. Typical of these are tests in the dynamics area, especially vibration and acceleration. The details of each individual test method will not be discussed here, but it is worthy to note that through the joint effort of dynamics engineers, both in industry and in the military, the dynamics portions of MIL-STD-810 reflect significant and improved technology. Although it is now obvious that additional progress still can and must be made in this area, the overall cooperative effort clearly illustrates what can be done when military and industrial environmental engineers are afforded the opportunity to communicate informally and resolve mutual problems.

The result of this effort is reflected in MIL-STD-810 in its present form. Those who may feel concern or alarm that MIL-STD-810 tests may not now suit their particular requirements are invited to compare a test from the new standard with a like test from one of the donor specifications. It will be found that the MIL-STD-810 tests provide more positive guidance and test technology than heretofore.

## SECTION IV

## APPLICATION

The environmental stress levels stated in the test methods of MIL-STD-810 represent what is generally considered to be the extreme conditions which usually constitute the minimum acceptable conditions for world wide military use. However, when designing to specific requirements where it is known that the environmental stress conditions are more severe or less severe than those given in the standard, the test limits may be adjusted as necessary. These, and other such details, must be determined by the engineer and included in the detail specification. It is not intended nor should it be expected that this document, prepared to cover the broad field of environmental testing, be a substitute for the engineer's decision-making responsibility and knowledge of known environmental stress conditions peculiar to his specific equipment or system.

In referring to specifications, it is pointed out that MIL-STD-810 is not a specification, nor is it intended to be. The contents of this document do not constitute the necessary ingredients for a specification. By military description a specification is the governing document for an item of hardware. It states the minimum acceptable requirements to insure that the item will do exactly what it is intended to do along with those acceptance tests and quality assurance provisions peculiar to the item. Since MIL-STD-810 is not applicable to any one specific item, or even a class of closely related items, it can not be considered a specification.

MIL-STD-810 should not be applied in retrospect. It is fully realized that the donor specifications are listed as applicable documents in many military procurement specifications. The intended application of MIL-STD-810 is for environmental testing related to new systems engineering and design. It may be assumed, however, that as MIL-STD-810 is more widely applied, these other specifications will gradually fall into disuse.

## SECTION V

## TRANSITION FROM "DONOR SPECIFICATIONS" TO MIL-STD-810

Confusion and uncertainty in performing the transition from those tests specified in MIL-T-5422, MIL-E-5272, and MIL-E-4970 to the tests outlined in MIL-STD-810 may be expected. In consideration of this fact, transition charts for each of the donor specifications are provided in tables I, II, and III. The tests stated in MIL-A-26669 are included in their entirety in MIL-STD-810 as Method 515. Specification MIL-A-26669 has been canceled.

TABLE I

Transition from MIL-T-5422 to MIL-STD-810

| MIL-T-5422 | | MIL-STD-810 |
|---|---|---|
| Para. Nr. | Environment | Method, Procedure, or Table |
| 4.1 | Temp. - Altitude | Method 504 |
| 4.2 | Vibration Part I<br>(designer must select G level)<br><br>Vibration Part II | Method 514, Table 514-I, 1B1, Step 1<br>(designer must select G level)<br><br>Method 514, Table 514-I, 1B1, Step 2 |
| 4.3<br>4.3.2.1<br>4.3.2.2 | Shock<br>Equipment<br>Mounting (crash safety) | Method 516<br>Procedure I (basic design test)<br>Procedure IV (crash safety test) |
| 4.4 | Humidity | Method 507 |
| 4.5 | Salt Spray | Method 509 |
| 4.6 | Explosion | Method 511 |
| 4.7 | Sand and Dust | Method 510 |
| 4.8 | Fungus | Method 508 |

TABLE II

Transition from MIL-E-5272 to MIL-STD-810

| MIL-E-5272 | | MIL-STD-810 |
|---|---|---|
| Para. Nr. | Environment | Method, Procedure, or Table |
| 4.1 | High Temperature | Method 501 |
| 4.2 | Low Temperature | Method 502 |
| 4.3 | Temperature Shock | Method 503 |
| 4.4 | Humidity | Method 507 |
| 4.5 | Altitude | Method 500, Procedure II |
| 4.6 | Salt Spray | Method 509 |
| 4.7 | Vibration | Method 514 |
| 4.7.1 | Discont'd. Use Proc. XII | N/A |
| 4.7.2 | Proc. II | Table 514-I, 1A1E to 500 ops only |
| 4.7.3 | Proc. III discont'd. Use Proc. XIII | N/A |
| 4.7.4 | Proc. IV | Table 514-I, 1C1A |
| 4.7.5 | Proc. V | Table 514-I, 1C1A |
| 4.7.6 | Proc. VI discont'd. | N/A |

| MIL-E-5272 | | MIL-STD-810 |
|---|---|---|
| Para. No. | Environment | Method, Procedure, or Table |
| Vibration Cont'd. | | |
| 4.7.7 | Proc. VII | Table 514-I, 1A1E |
| 4.7.8 | Proc. VIII | Table 514-I, 1A1E |
| 4.7.9 | Proc. IX discont'd. Use Proc. XII | N/A |
| 4.7.10 | Proc. X discont'd. Use Proc. XII | N/A |
| 4.7.11 | Proc. XI discont'd. Use Proc. XII | N/A |
| 4.7.12 | Proc. XII | Table 514-I, 1A1,B,C,D or E<br>1B1,B,C,D or E<br>1B1A |
| 4.7.13 | Proc. XIII | Table 514-I, 1C1A |
| 4.7.14 | Proc. XIV | |
| | Aircraft | Table 514-I, 1A1E |
| | Rocket (test now obsolete) | See criteria for Air Launched & Ground Launched Missiles Table 514-I, Equip Class 3 & 4. |
| 4.8 | Fungus | Method 508 |
| 4.9 | Sunshine | Method 505 |
| 4.10 | Rain | Method 506 |

| MIL-E-5272 | | MIL-STD-810 |
|---|---|---|
| Para. No. | Environment | Method, Procedure, or Table |
| 4.11 | Sand and Dust, Proc. I, II, & III | Method 510 |
| 4.12 | Immersion | Method 512, Proc. I |
| 4.13 | Explosion | Method 511 |
| 4.14 | Temperature - Altitude, Proc. I & II | Method 504 |
| 4.15 | Shock | |
| 4.15.1 | Proc. I discont'd. Use Proc. IV | N/A |
| 4.15.2 | Proc. II discont'd. Use Proc. V | N/A |
| 4.15.3 | Proc. III | Obsolete, not carried forward in MIL-STD-810 |
| 4.15.4 | Proc. IV | Method 516, Proc. V |
| 4.15.5 | Proc. V | Method 516 as below |
| 4.15.5.1 | Equipment | Method 516, Proc. I (basic design test) |
| 4.15.5.2 | Equipment, Crash Safety | Method 516, Proc. IV (crash safety test) |
| 4.16 | Acceleration | |
| 4.16.1 | Proc. I | Method 513, Proc. I & II |

| MIL-E-5272 | | MIL-STD-810 |
|---|---|---|
| Para. Nr. | Environment | Method, Procedure, or Table |
| Acceleration Cont'd. | | |
| 4.16.2 | Proc. II discont'd. Use Proc. III | N/A |
| 4.16.3 | Proc. III | Method 513, Proc. I & II |

TABLE III

Transition from MIL-E-4970 to MIL-STD-810

| MIL-E-4970 | | MIL-STD-810 |
|---|---|---|
| Para. Nr. | Environment | Method, Procedure, or Table |
| 4.1 | High Temperature | |
| 4.1.1 | Proc. I | Method 501 |
| 4.1.2 | Proc. II | Method 501 |
| 4.1.3 | Proc. III | Method 501 |
| 4.2 | Low Temperature | |
| 4.2.1 | Proc. I | Method 502 |
| 4.2.2 | Proc. II | Method 502 |
| 4.2.3 | Proc. III | Method 502 |
| 4.3 | Humidity | |
| 4.3.1 | Proc. I | Method 507 |
| 4.4 | Low Pressure | |
| 4.4.1.1 | Proc. I | Method 500, Proc. I |
| 4.4.1.2 | Proc. II | Method 500, Proc. I |
| 4.5 | Salt Fog | Method 509 |

| MIL-E-4970 | | MIL-STD-810 |
|---|---|---|
| Para. Nr. | Environment | Method, Procedure, or Table |
| 4.6 | Vibration | |
| 4.6.1 | Proc. I discont'd. Use Proc. IV | N/A |
| 4.6.2 | Proc. II discont'd. Use Proc. V | N/A |
| 4.6.3 | Proc. III discont'd. Use Proc. VI | N/A |
| 4.6.6 | Proc. IV | Method 514, Table 514-I, 5-5A |
| 4.6.7 | Proc. V | Method 514, Table 514-I, 5-5B |
| 4.6.8 | Proc. VI | Method 514, Table 514-I, 6-6A |
| 4.6.9 | Proc. VII | Method 514, Para. 5.5<br>All ground equipment gets transportation test Method 514, Table 514-I, 7-6A, See Para 5.7. |
| 4.7 | Fungus, Proc. I | Method 508 |
| 4.8 | Sunshine, Proc. I | Method 505 |
| 4.9 | Rain, Proc. I | Method 506 |
| 4.10 | Sand and Dust, Proc. I and II | Method 510 |
| 4.11 | Explosion | Method 511 |

| MIL-E-4970 | | MIL-STD-810 |
|---|---|---|
| Para. Nr. | Environment | Method, Procedure, or Table |
| 4.12 | Shock | Method 516 |
| 4.12.1 | Proc. I | Proc. I |
| 4.12.2 | Proc. II | Proc. II or III |
| 4.12.3 | Proc. III discont'd. Use Proc. VII | N/A |
| 4.12.4 | Proc. IV | Proc. I |
| 4.12.5 | Proc. V discont'd. Use Proc. IV | N/A |
| 4.12.6 | Proc. VI | Proc. VI |
| 4.12.7 | Proc. VII | Proc. III |
| 4.13 | Immersion, Proc. I | Method 512, Proc. I |

## SECTION VI

## DEVELOPMENT OF FUTURE TEST METHODS

Procedures for complete environmental testing to the requirements for space vehicles, and meaningful test methods for combined environmental testing should be introduced into MIL-STD-810 as quickly as the technology can be developed.

A. Space Environment Testing. Tests and facilities designed to simulate conditions encountered by earth-orbiting and space vehicles involve sophisticated combined environments of the highest order. Facilities or "space" chambers capable of generating the entire gamut of space conditions do not presently exist and may never be achieved in earth-bound laboratories. Examples of conditions which present formidable simulation problems are weightlessness and the velocities required to simulate hits by meteoroids. Although not impossible, the effects on both vehicle and occupant resulting from cosmic and nuclear radiation will be difficult to simulate. The life history of a space vehicle may be divided into four basic categories as follows:

1. Earth Environments.
2. Earth-Orbiting Environments.
3. Space Flight Environments.
4. Entry and Landing Environments (Earth and Other Bodies).

The four basic categories may be further reduced with those environments parent to each phase, as follows:

1. Earth Environments
    a. Transportation, Handling, and Storage Phase
        (1) Pressure
        (2) High Temperature
        (3) Low Temperature
        (4) Temperature Shock

(5) Sunshine

(6) Rain

(7) Humidity

(8) Fungus

(9) Salt Fog

(10) Sand & Dust

(11) Acceleration

(12) Shock

(13) Vibration

b. Launch Phase

(1) Acceleration

(2) Vibration

(3) Shock

(4) Explosion

(5) Acoustical Noise

(6) Temperature

(7) Pressure

c. Transition Phase

(1) All environments parent to launch phase plus:

(2) Rain

(3) Hail

(4) Wind

(5) Turbulence

(6) Icing

(7) Geomagnetism

(8) Ozone

2. Earth-Orbiting Environments

a. Low Pressure

b. Van Allen Radiaiton

*c. Cosmic & Solar Radiation

d. Sputtering and Sublimation

e. Low Temperature

*f. Weightlessness

g. Explosion

h. Vibration (marginal importance)

*i. Meteoroid Hits

3. Space Flight Environments

*a. Weightlessness

*b. Cosmic, Solar, and Nuclear Radiation

*c. Meteoroid Hits

d. Explosion

e. Low Pressure

f. Temperature

g. Vibration (marginal importance)

4. Entry and Landing Environments (Earth and Other Bodies).

   a. Shock

   b. Vibration

   c. Deceleration

   d. Ion Sheath

   e. Re-entry Temperature (Skin Heating)

   f. Ablation

   g. Atmosphere of the Body.

   h. Surface Characteristics

*Those environments marked with an asterisk indicate conditions which will be extremely difficult, if not impossible, to simulate in an earth-bound facility. Although many of the environments may be simulated singly or in simple combinations, a true combined reproduction of all concurring environments will be highly complex.

It is recognized that environments other than those listed al. e exist in both natural and induced forms. The conditions listed constitute, in varying degrees, the more significant environments. The concurrence and resulting interactions of these natural and induced environments pose the true problem in developing a test program.

The selection of realistic stress levels for the space environments is particularly difficult. That the article is being "overtested" or "undertested" is a commonly-heard claim. How then should the test be organized and numbers for stress levels be determined? MIL-STD-810 can provide only a degree of guidance. Some of the stress levels are the result of analyzing measured data; others were determined empirically. In organizing the test, users of the document should consider only those test environments that reflect actual anticipated service conditions. Those conditions which would adversely affect the item or most probably induce a malfunction should be given emphasis.

An approach to space environmental testing is presented in Method 517, "Low Pressure-Solar Energy" of MIL-STD-810. Although the guide lines are

nebulous and numbers for the total environment are lacking, the test does represent a sincere attempt to present the means for bridging the gap between the Earth's environments and the environments of space.

B. Combined Environmental Testing. Environments, both natural and induced, in various combinations and varying degrees of severity prevail throughout the Universe. The most common of these are temperature and pressure. Considering these as basic, more and more environments may be added until the number of possible combinations exceeds all sensible limits. Again, the test must be organized so that the more probable and damaging environments are combined. This philosophy is, for the most part, contrary to the present organization of environmental testing for qualification approval, first article, and reliability testing. In such tests, the test item is subjected to single tests of increasing damage potential for the admitted purpose of obtaining the "most mileage" from the test item.

To date, discussions with military, and especially industrial environmental engineers, indicate a passive resistance or general reluctance to include combined tests in MIL-STD-810. The cost of combined environmental test facilities and, as previously discussed, the development of a meaningful test program contribute largely to this feeling. The correlation and comparison of single vs. combined environmental testing should be brought under intensive study. Until such time, the subject will remain controversial, and ignorance will prevail.

To a limited degree MIL-STD-810 does contain tests for combined environments. These environments by test method are illustrated in table I. Although some tests are conducted at room temperature, room pressure, uncontrolled humidity etc., which do not constitute accelerated stress conditions as combined with the stressed environment, they are shown to bring the degree of combining the environments into true focus.

TABLE IV

EXTENT OF COMBINED TESTS AVAILABLE IN MIL-STD-810

| Test from MIL-STD-810 | | Environments in Combination | |
|---|---|---|---|
| Test No. | Title | Controlled Environment of Concern | Room Ambient or Uncontrolled Environment |
| 500 | Low Pressure | Low Pressure | Temperature<br>Humidity |
| 501 | High Temperature | High Temperature<br>Low Humidity | Pressure |
| 502 | Low Temperature | Low Temperature | Humidity<br>Pressure |
| 503 | Temperature Shock | High & Low Temperature Cycling | Humidity<br>Pressure |
| 504 | Temperature-Altitude Cycling | Low Temperature<br>High Temperature<br>Low Pressure<br>Humidity (where req) | Humidity (except where specified) |
| 505 | Sunshine | Solar Radiation | Pressure<br>Humidity |
| 506 | Rain | Rain | Temperature<br>Pressure<br>Humidity |
| 507 | Humidity | Temperature<br>Humidity | Pressure |
| 508 | Fungus | Fungus Culture<br>Temperature<br>Humidity | Pressure |
| 509 | Salt Fog | Salt Solution<br>Temperature | Pressure<br>Humidity |
| 510 | Sand & Dust | Sand & Dust<br>Temperature<br>Humidity | Pressure |
| 511 | Explosion | Fuel Mixture<br>Temperature<br>Low Pressure | Humidity |
| 512 | Immersion (Leakage) | Immersion Liquid<br>Temperature<br>Pressure | |
| 513 | Acceleration | G level | Temperature<br>Pressure<br>Humidity |

Cont'd. on next page

TABLE IV Cont'd.

| Test No. | Title | Controlled Environment of Concern | Room Ambient or Uncontrolled Environment |
|---|---|---|---|
| 514 | Vibration | G Level & Frequency<br>High or Low Temperature where specified | Temperature<br>Pressure<br>Humidity |
| 515 | Acoustical Noise | Noise Level | Temperature<br>Pressure<br>Humidity |
| 516 | Shock | G-Level | Temperature<br>Pressure<br>Humidity |
| 517 | Low Pressure-Solar Energy | Low Pressure<br>Low Temperature<br>Solar Energy | Humidity |

## SECTION VII

## SUMMARY

Together the military and industry have resolved many environmental problems in the development of MIL-STD-810. However, when considering the broad scope of this effort, some differences of opinion are bound to prevail. Some controversial points may never be resolved.

In an organization such as the Aeronautical Systems Division with its many systems project offices and their responsible system development contractors, environmental problems arise almost daily, especially in the initial phase when the system environmental compatibility for a new flight vehicle is being developed. It is essential that constant surveillance and liaison across this vast military-contractor effort be maintained so that MIL-STD-810 can be kept up to date. If, through the use of this standard, deficiencies are noted, or if new criteria and methodology are developed for which there is a general need, it is suggested that recommendations be made for upgrading the standard. The importance of this team effort can not be minimized.

It is recognized, with no apology intended, that MIL-STD-810 in its present form is not a panacea for every problem associated with environmental testing. The contents of the test methods are not based on any newly performed basic research program or revolutionary findings which would challenge the state of the art. It does bring together, in one document, standard test methods that are at least current with the state of the art.